

What would happen to Superstorm Sandy in a warmer climate?

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EXTREME RAINFALL AND CLIMATE (2013-2015, PI: W. Lau, Co-I: W. K. Tao, Y. Zhou and J. Wu)

Zhou, Yaping, W.K. M. Lau, and G. J. Huffman, 2015: Mapping TRMM rainfall data into average recurrence interval for monitoring extreme precipitation events. *J. Appl. Meteor. Climatol.*, **54**, 979–995, doi: <http://dx.doi.org/10.1175/JAMC-D-14-0269.1>

Zhou, Y., Wu, D., and W. K. M. Lau, 2015: Scale-dependence of land-atmosphere interactions in wet and dry regions as simulated by NUWRF over the Southwestern and South Central US., *J. Hydromet.*, **17**, 2121-2136, DOI: 10.1175/JHM-D-16-0024.1

Wu, H.-T. J., and W. K.-M. Lau (2016), Detecting climate signals in precipitation extremes from TRMM (1998– 2013)— Increasing contrast between wet and dry extremes during the “ global warming hiatus” *Geophys. Res. Lett.* , **43**, doi:10.1002/2015GL067371.

Lau, W. K. M., J. J. Shi, W. K. Tao, and K. M. Kim (2016), What would happen to Superstorm Sandy under the influence of a substantially warmer Atlantic Ocean? *Geophys. Res. Lett.* , **42**, doi:10.1002/2015GL067050.

TROPICAL CONVECTION, CLOUD SYSTEMS AND EXTREME PRECIPITATION EVENTS (2016-2018, PI: W. Lau, Co-I: K. M. Kim, W. K. Tao and J. Chern)
Poster 219, Tuesday, Oct 25.

Hurricane Sandy was the deadliest and most destructive [hurricane](#) of the [2012 Atlantic hurricane season](#), as well as the second-costliest hurricane in United States history.

Classified as the eighteenth named storm, tenth hurricane and second major hurricane of the year, Sandy was a [Category 3](#) storm at its peak intensity when it made landfall in Cuba. While it was a [Category 2](#) storm off the coast of the Northeastern United States, the storm became the [largest Atlantic hurricane](#) on record (as measured by diameter, with winds spanning 1,100 miles (1,800 km)).^{[2][3]}

Damage was estimated at [\\$68 billion](#) (2013 USD), a total surpassed only by [Hurricane Katrina](#). At least 286 people were killed along the path of the storm in seven countries.

Frequently asked questions about Superstorm Sandy

Why was it so destructive?

Why was the track so unusual? Why was the storm so big?

Was it just natural variability? A chance occurrence of a perfect storm?

Did global warming play any role?

Even a rare natural occurrence (perfect storm) may repeat itself in the future,

What would happen to Superstorm Sandy in a future warmer world?

Attribution of Extremes Weather to Climate Change

	Thermodynamically induced	Dynamically induced
Natural/ Internal Variability	✓	✓
Forced/ Anthropogenic	✓?	??

For tropical cyclones

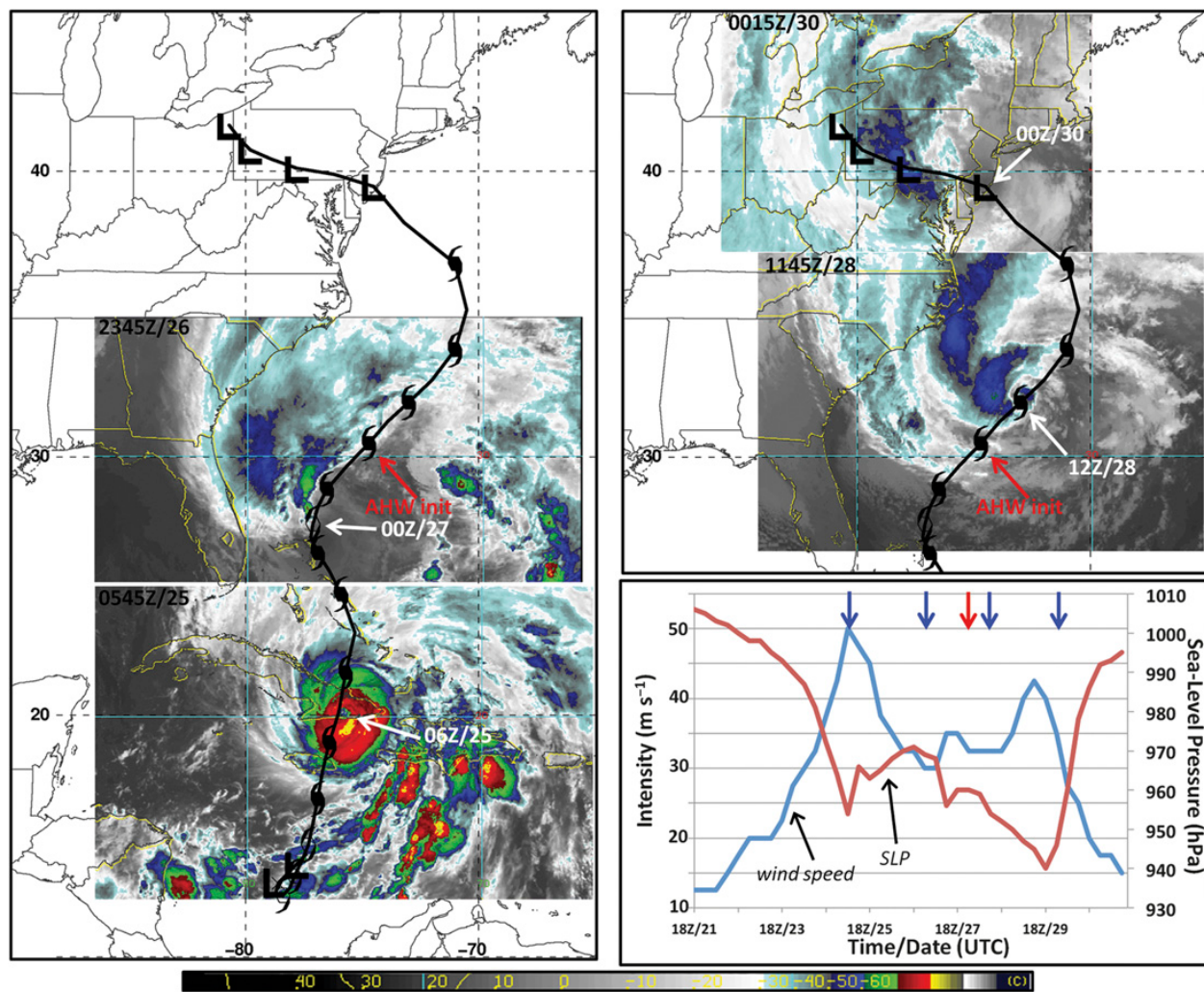
Thermodynamics

driver: induced by changes in SST and fluxes (radiative, latent and sensible) at earth surface

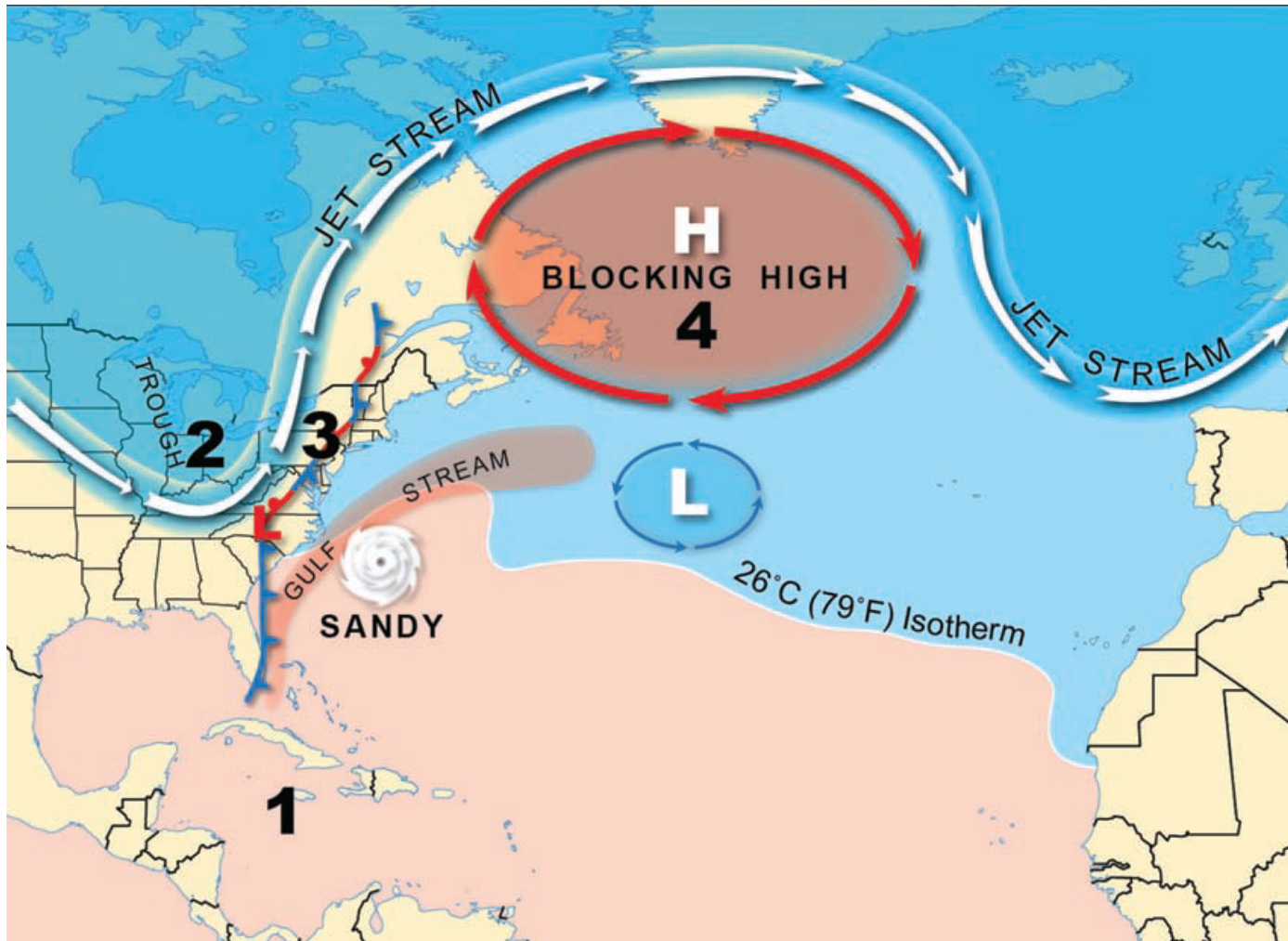
Dynamic

drivers: changes in vertical wind shear, steering flow shifts caused by changes in circulation, extratropical stationary planetary waves (blocking , jetstream, storm tracks...)

Given present-day atmospheric conditions that gave rise to SS, what would happen to SS-like storms in a future climate with warmer Atlantic SST?



00Z Oct-22-23 Easterly wave/Tropical Depression
 06 Oct 25 Cat-3 storm over Cuba
 00Z Oct 27 Began ET
 06Z Oct 29 NW turn
 18Z/29 -00Z/30 Cat -2, landfall over N. New Jersey



Large-scale environmental conditions conspiring to produce Superstorm Sandy (Halverson and Rabenhorst, 2014)

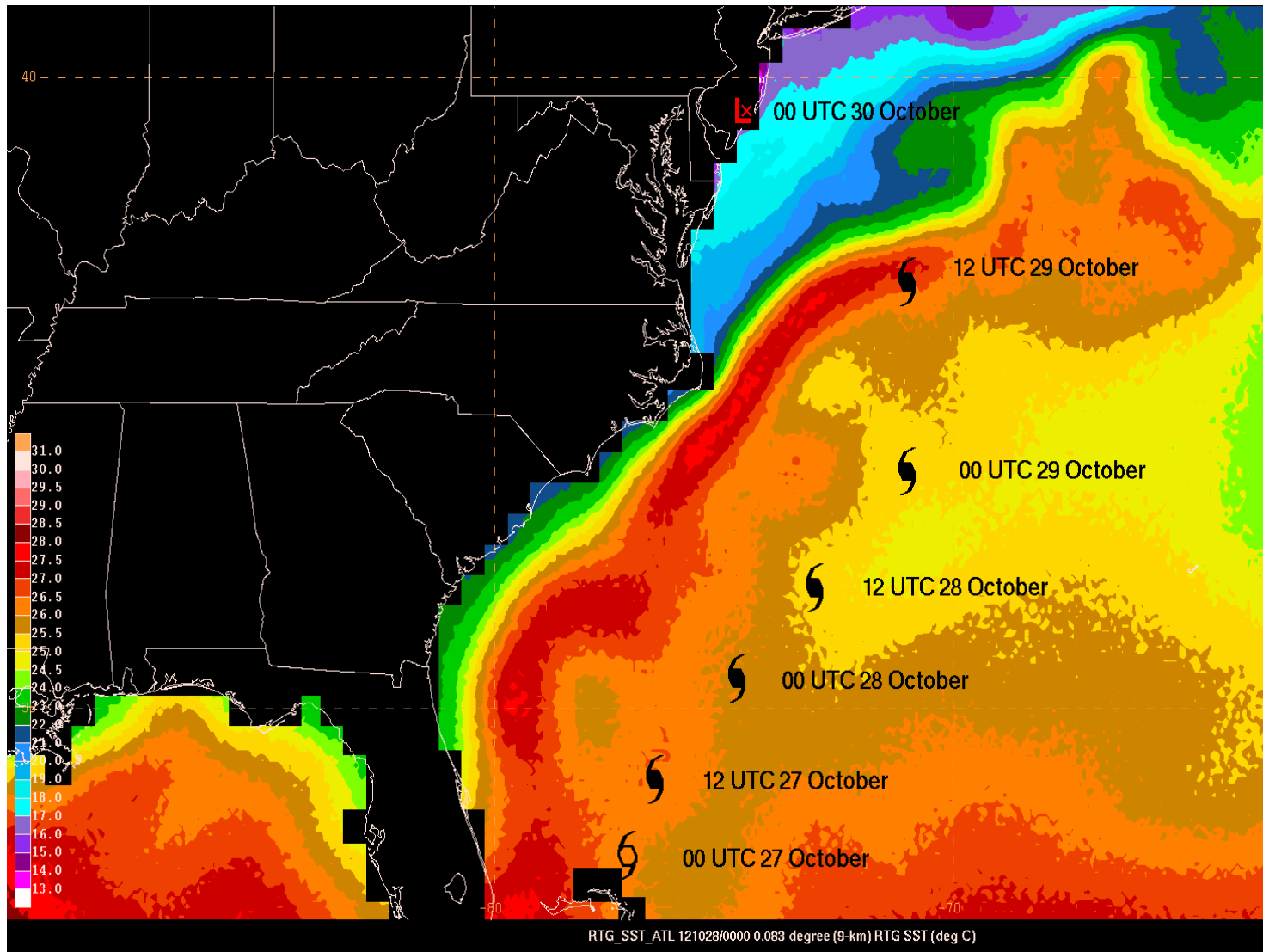
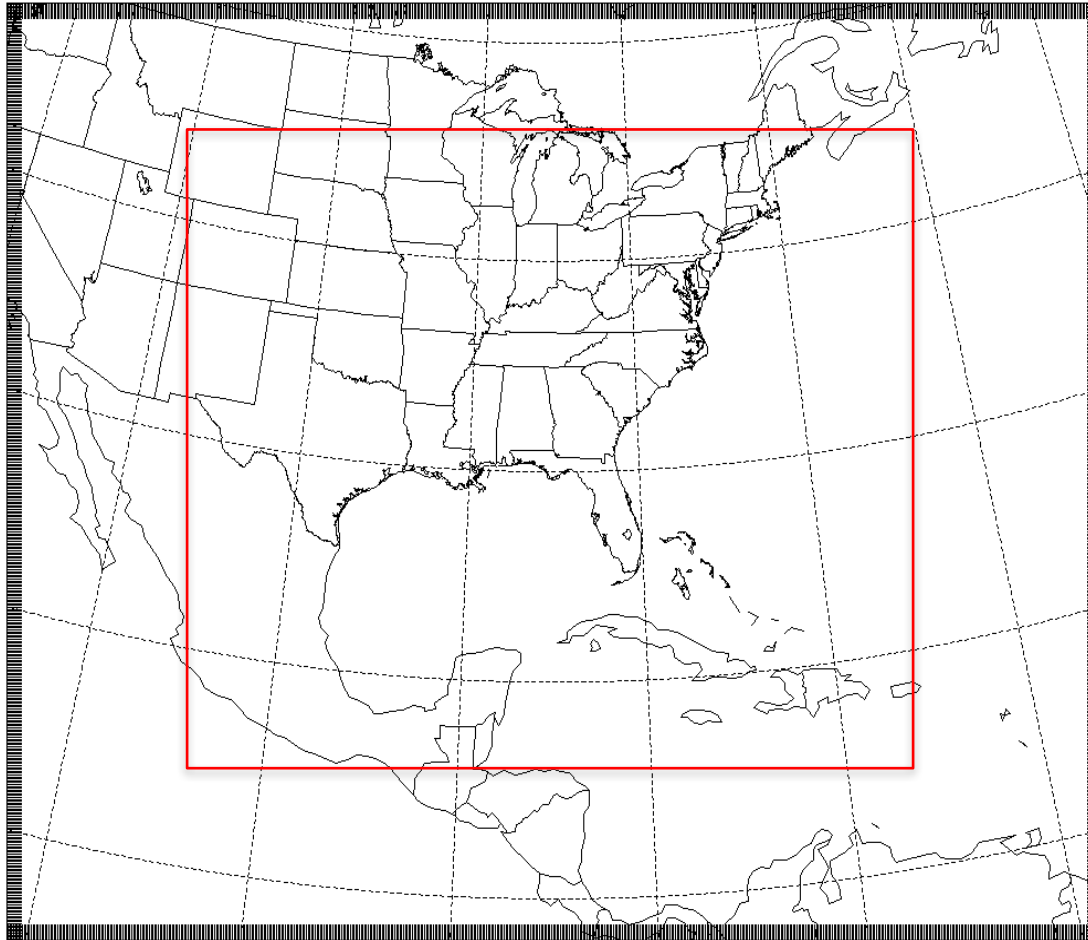


Figure 10. SSTs (°C) on 28 Oct 2012 from the NCEP real-time global 1/12° analysis, with the best track of Sandy plotted at 12-h intervals.



The nested domain used in the simulations 22-23 Oct start,
9-10 day integration, 9 km resolution (inner domain) Nu-WRF

- Prescribed future Atlantic SST from CMIP5 MMM 2xCO₂ projections
- Same initial and boundary atmospheric conditions as present-day
- No projected change in forcing due to dynamics, i.e., vertical wind shear..

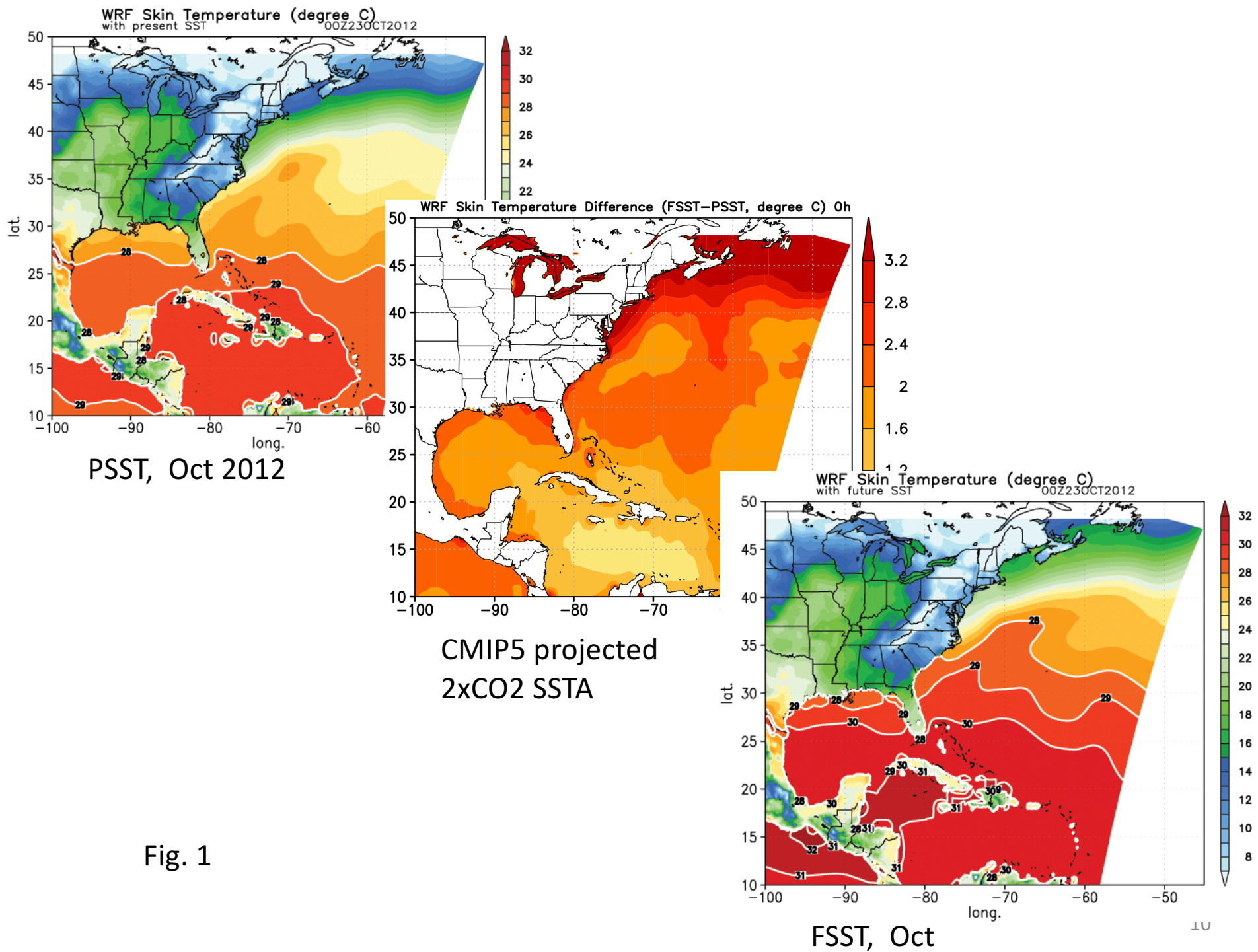
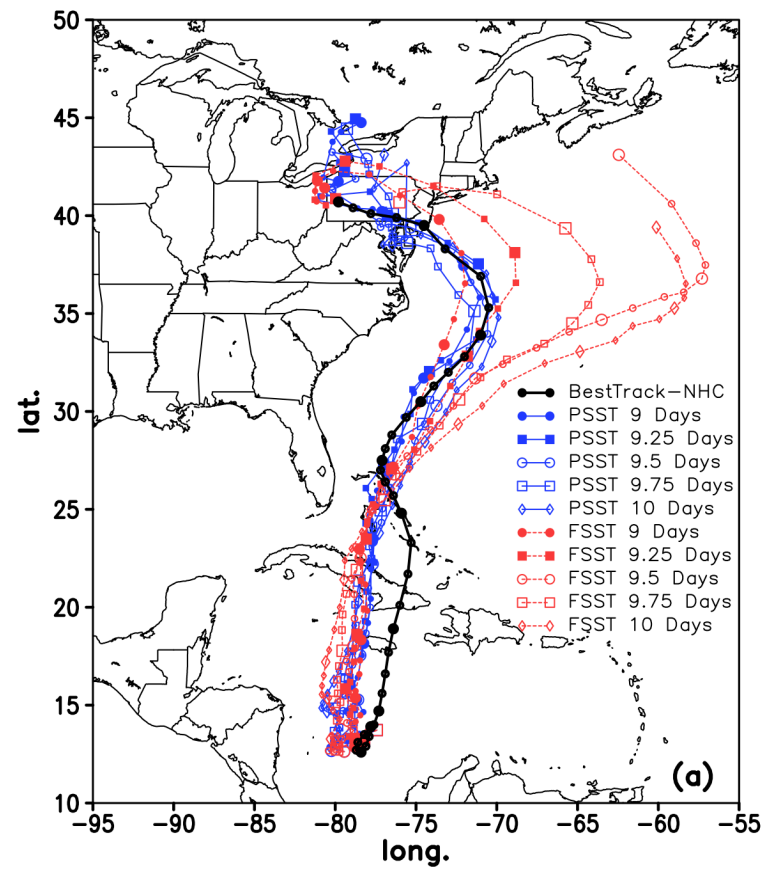
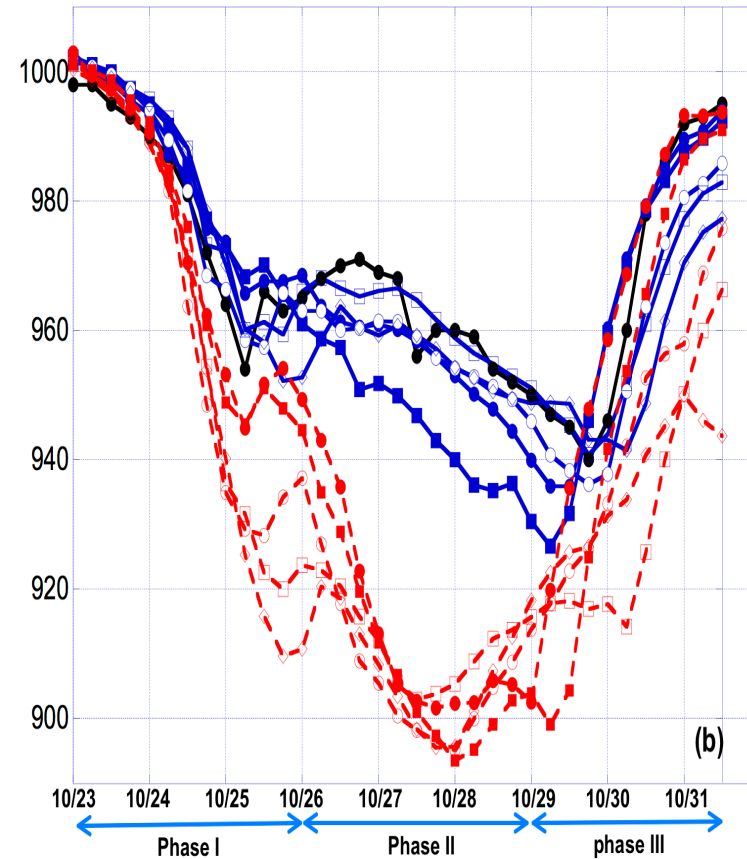


Fig. 1

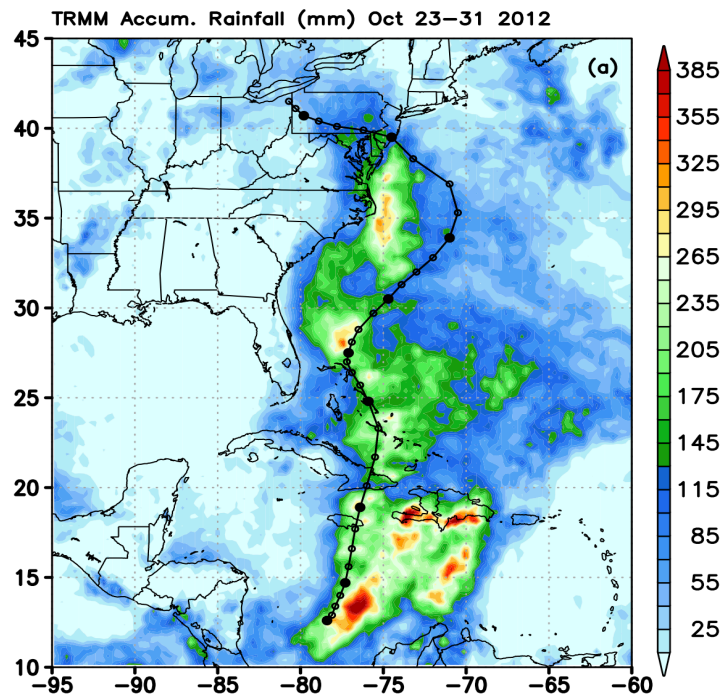
A bifurcation in model response depending on initial start time



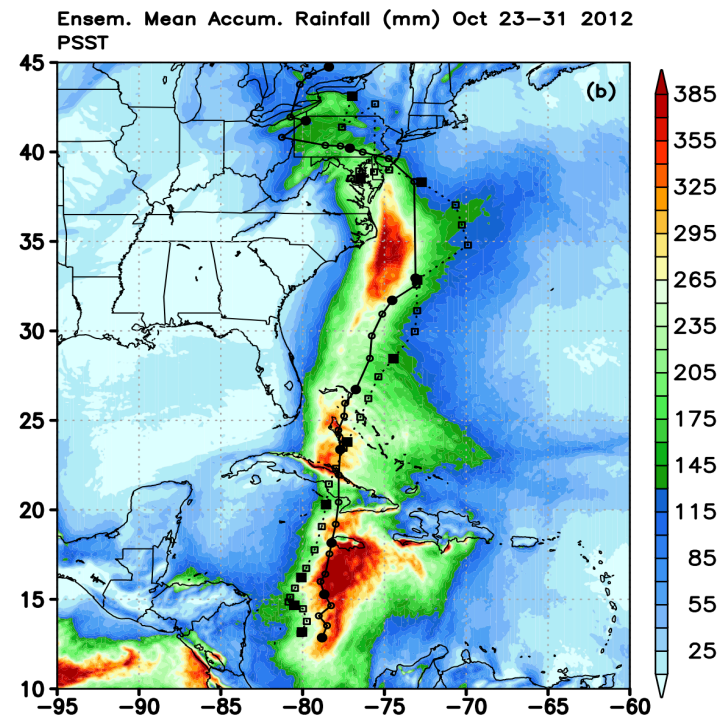
PSST
FSST_NW
FSST_NE

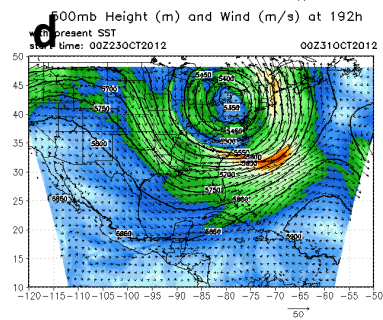
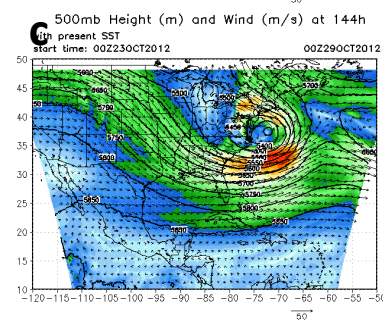
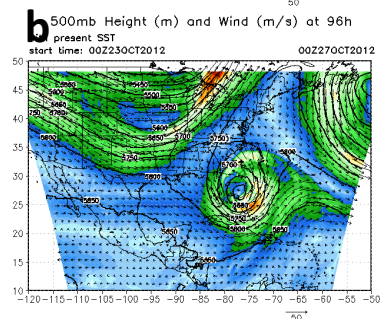
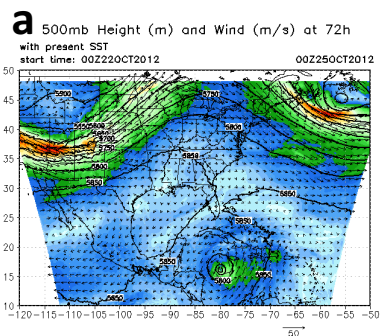


TRMM

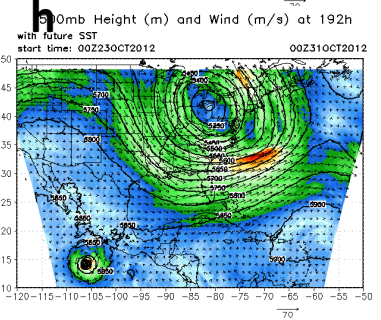
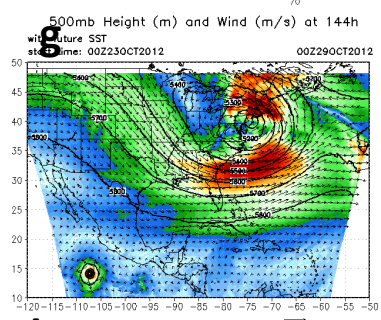
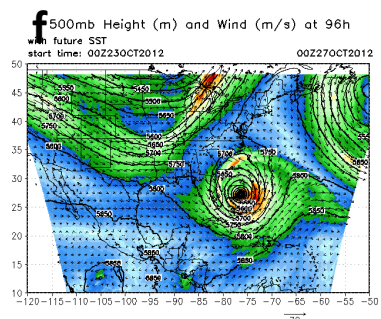
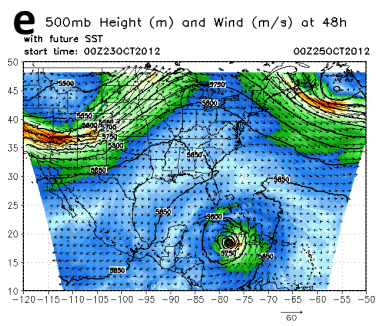


PSST

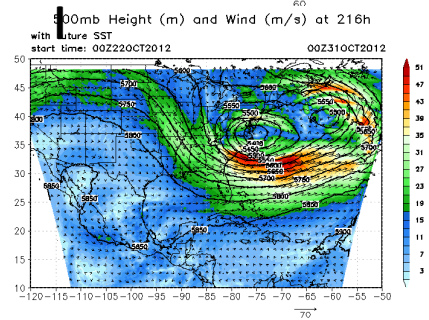
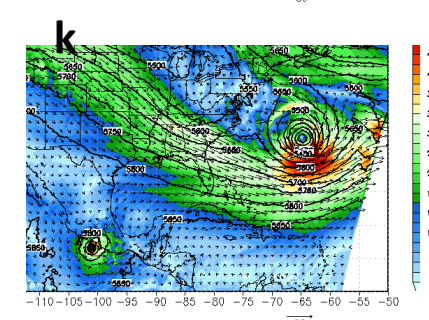
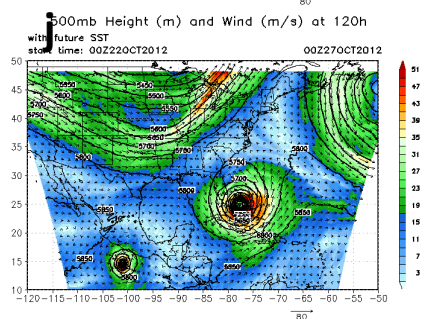
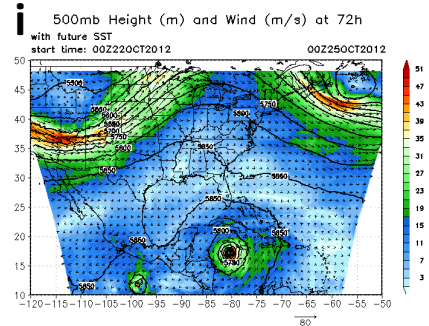




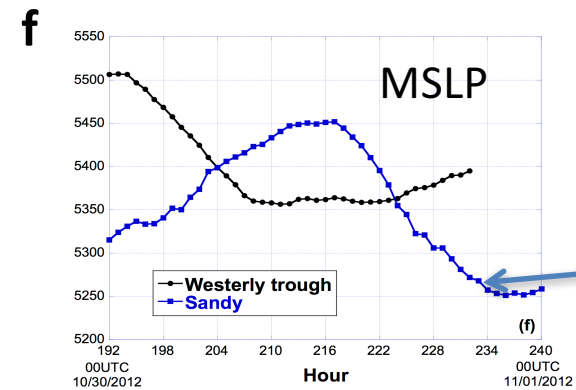
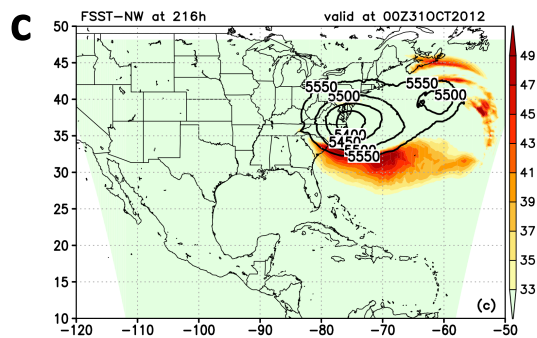
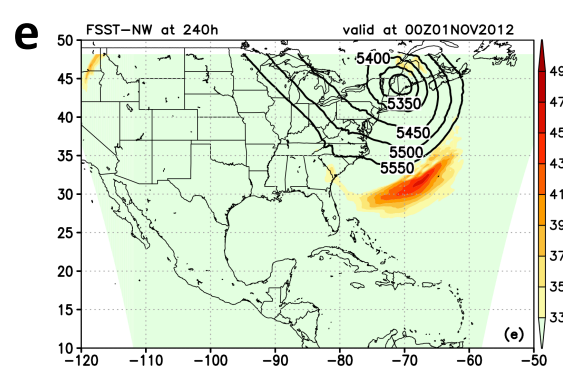
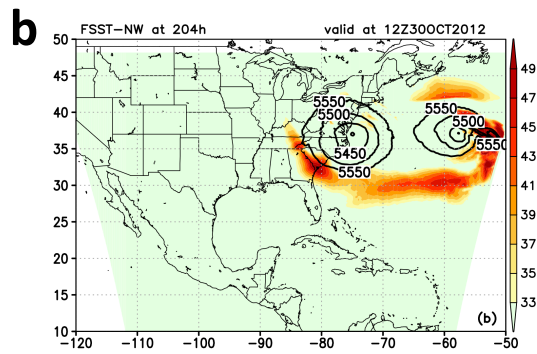
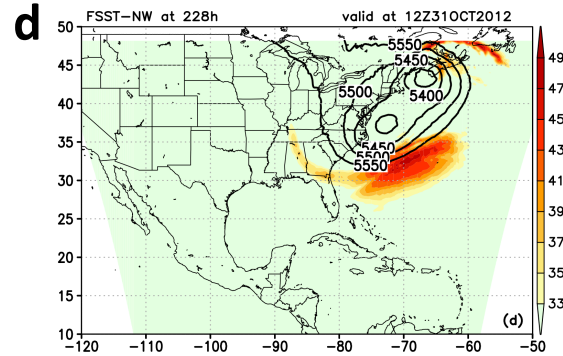
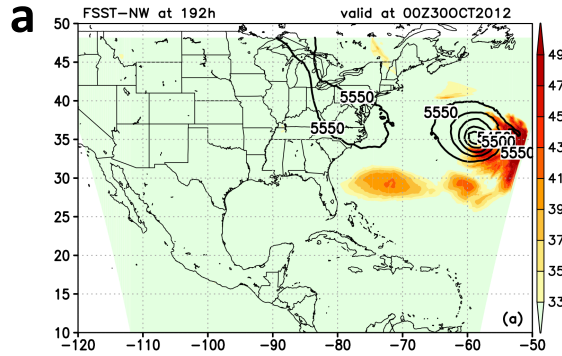
PSST



FSST_NW



FSST_NE



The Fujiwhara effect

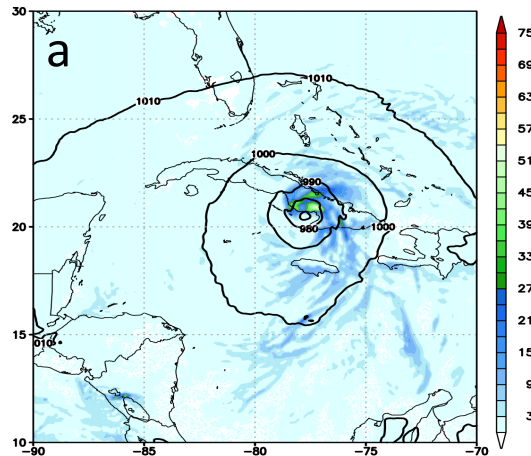
SS Re-intensification due to:

1. Warmer coastal SST,
2. Fujiwhara effect

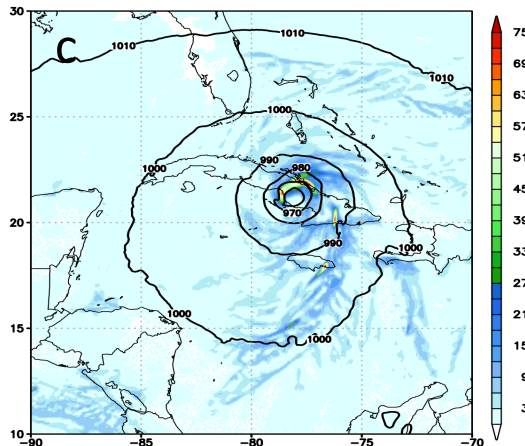
FSST_NE

00UTC 25 Oct 2012

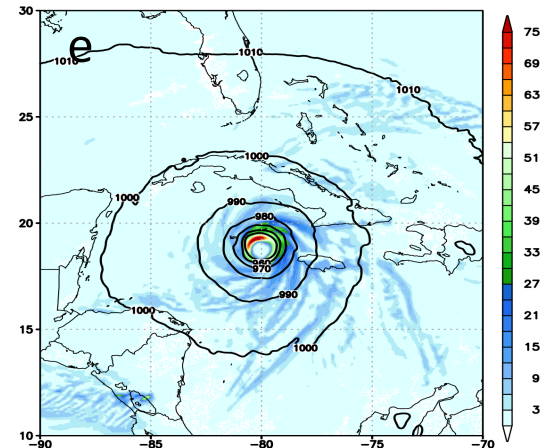
Rainrate (mm/h) and SLP (hPa) at 60h
with PSST valid at 12Z25OCT2012



Rainrate (mm/h) and SLP (hPa) at 60h
with FSST-NW valid at 12Z25OCT2012

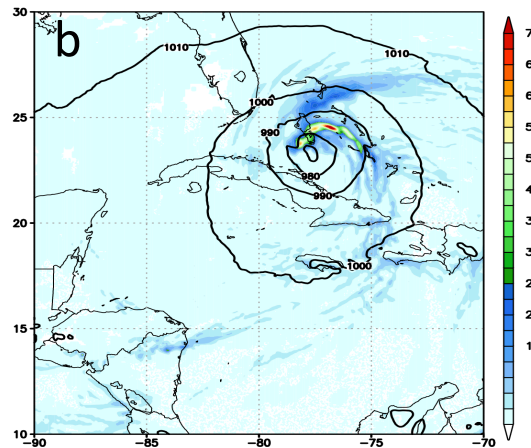


Rainrate (mm/h) and SLP (hPa) at 84h
with FSST-NE valid at 12Z25OCT2012

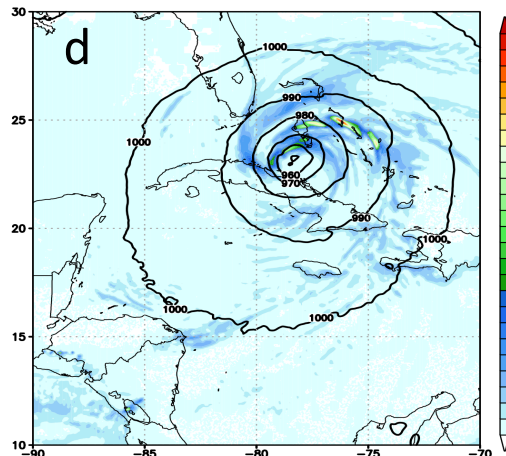


00UTC 26 Oct 2012

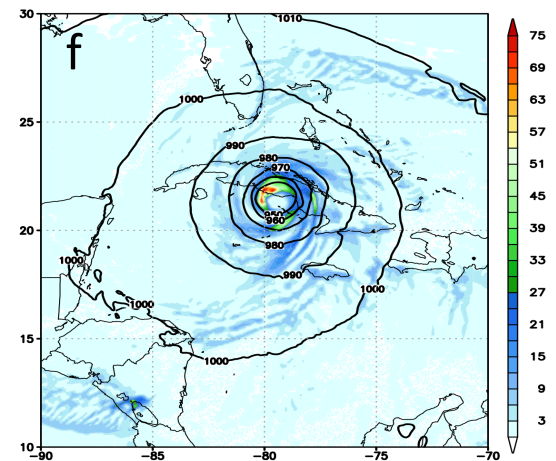
Rainrate (mm/h) and SLP (hPa) at 72h
with PSST valid at 00Z26OCT2012



Rainrate (mm/h) and SLP (hPa) at 72h
with FSST-NW valid at 00Z26OCT2012



Rainrate (mm/h) and SLP (hPa) at 96h
with FSST-NE valid at 00Z26OCT2012



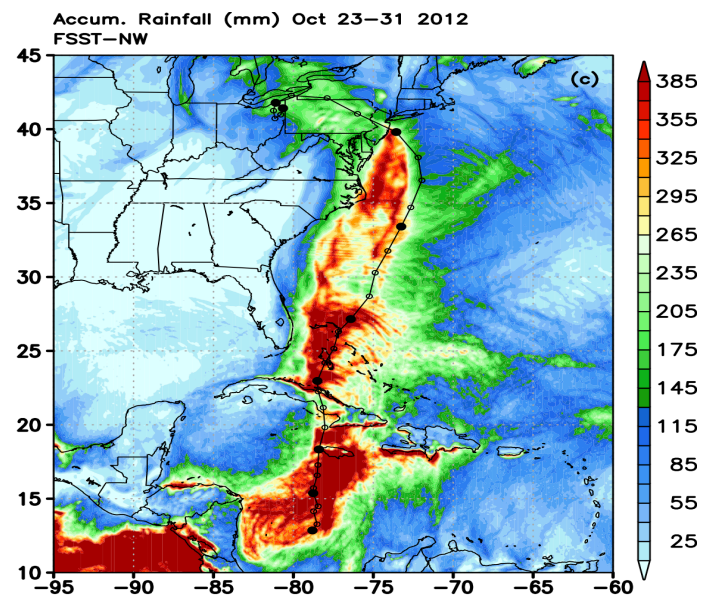
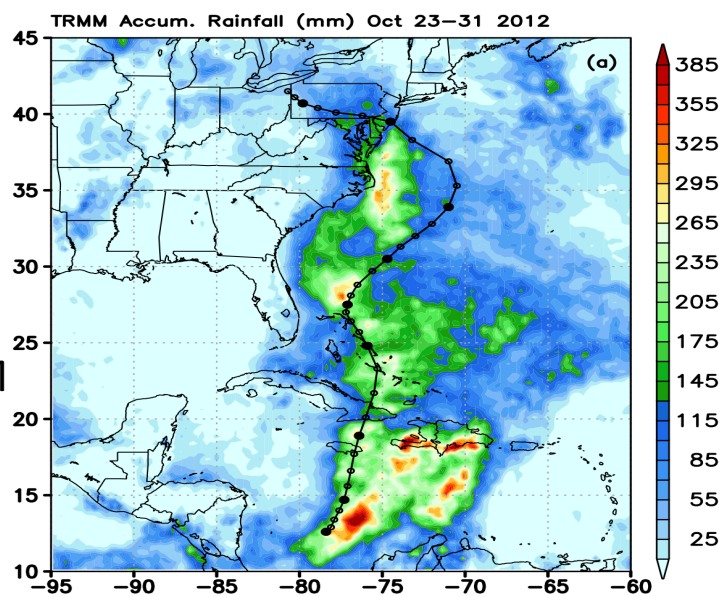
PSST

FSST-NW

FSST-NE

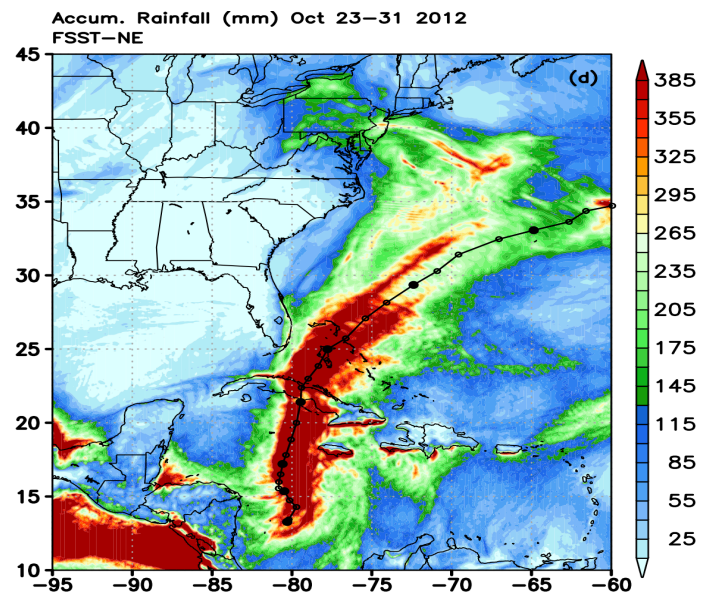
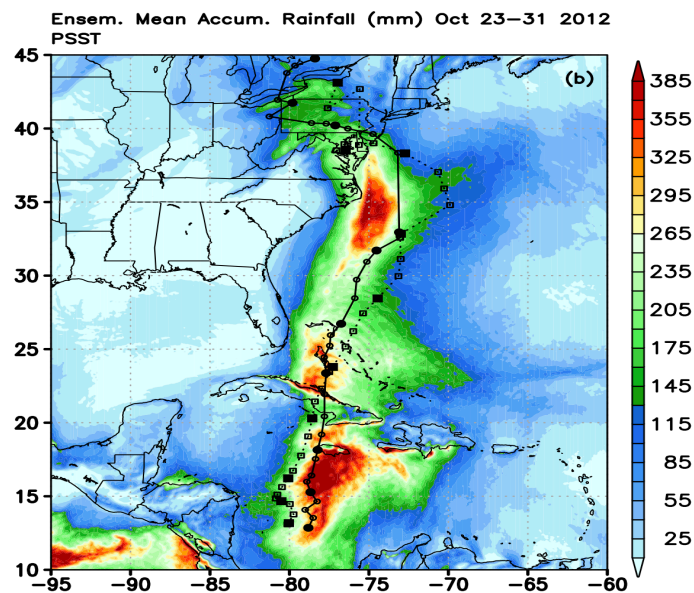
slower propagation

TRMM
Obs



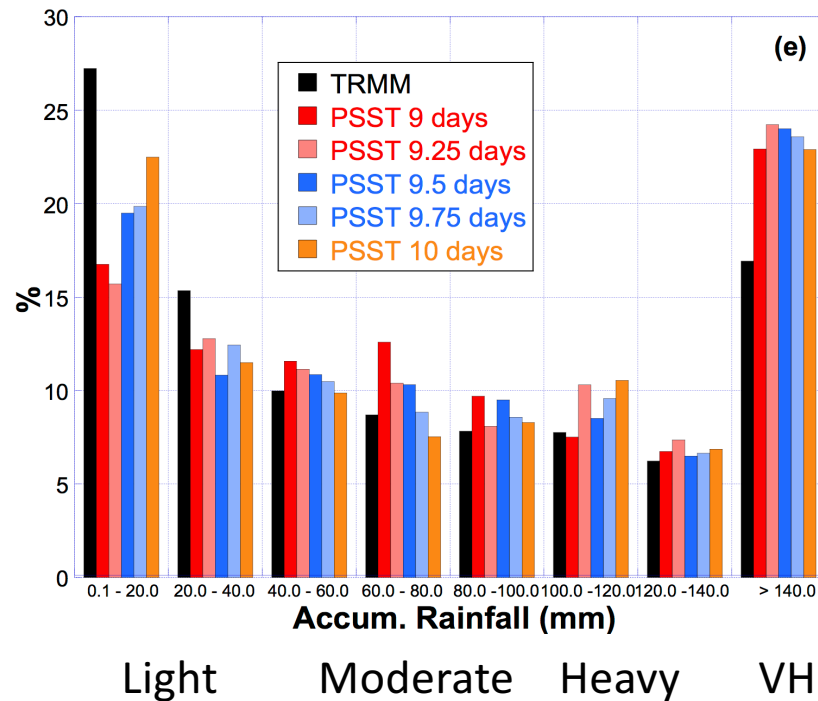
FSST_NW

PSST

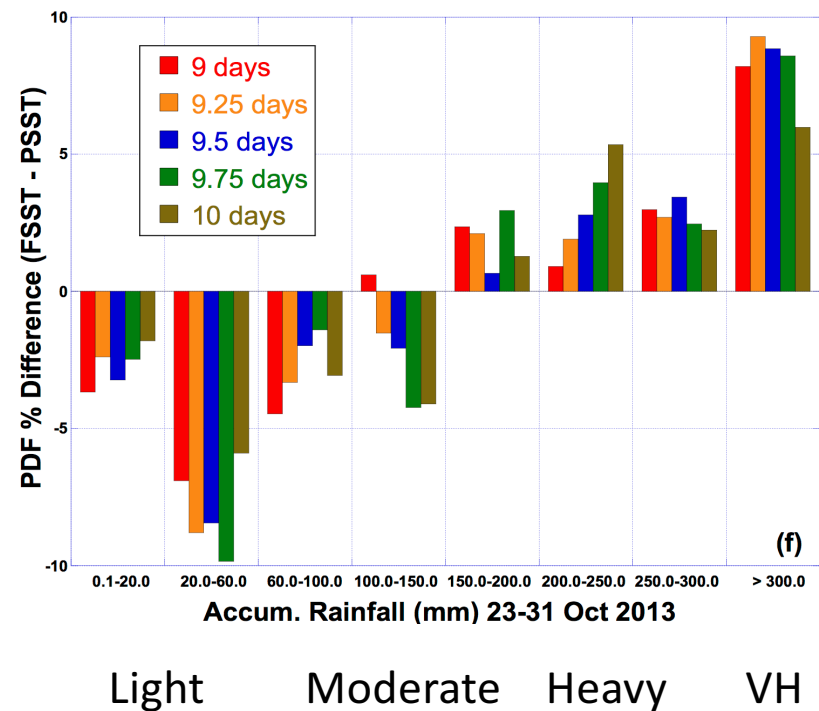


FSST_NE

Life-Cycle Precipitation Intensity Change

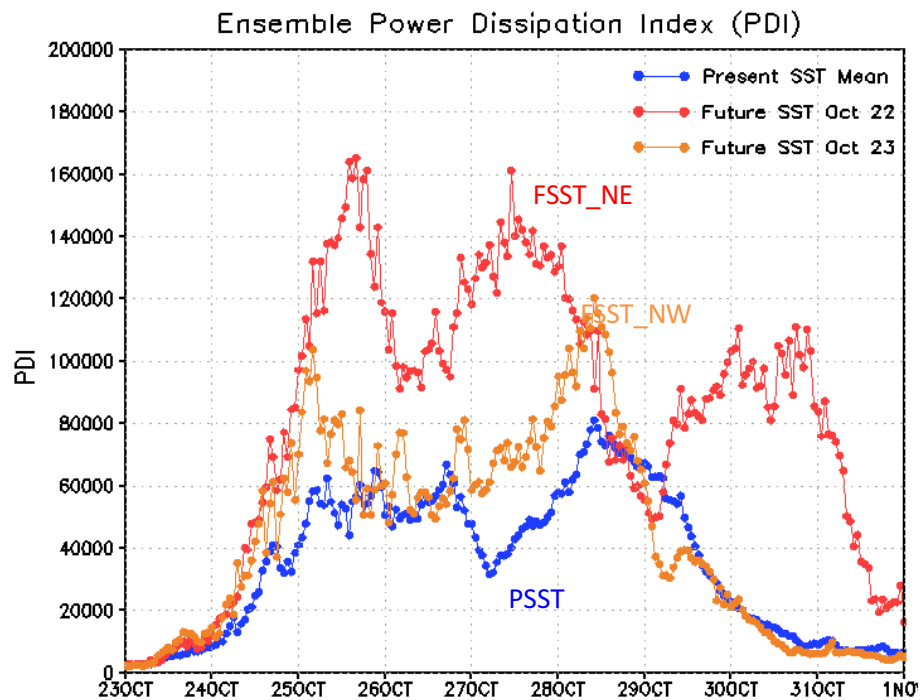


PSST v. TRMM



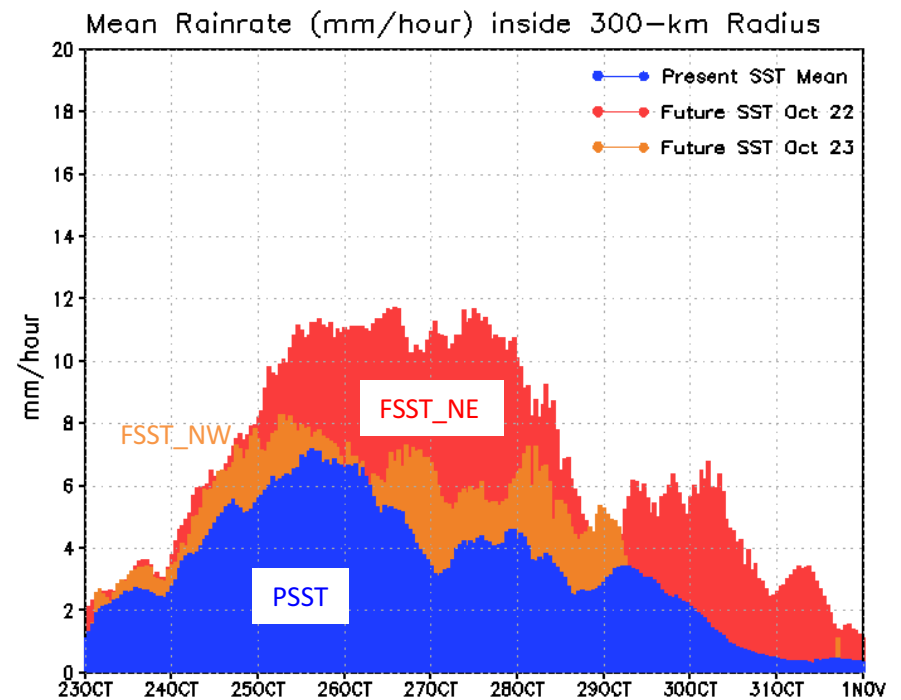
FSST-minus-PSST

$$PDI = \int_0^T V_{max}^3 dt$$



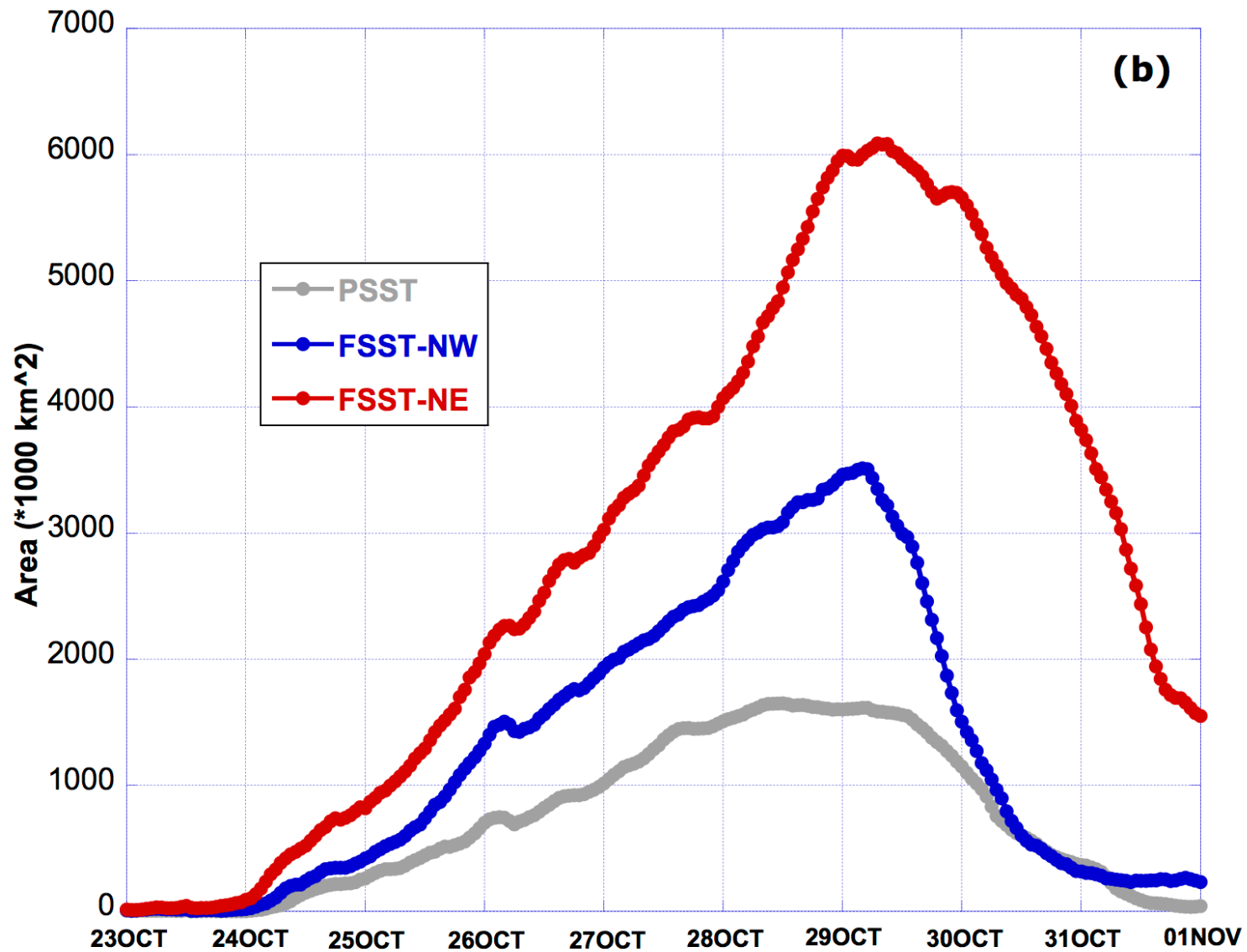
FSST_NW + 50%
FSST_NE +100-150%

Mean rainrate within 300 Km radius



FSST-NW +10-50%
FSST-NE +80-180%

Storm size = area with 10 m sustained winds $>17 \text{ ms}^{-1}$



Sandy movies:

PSST

FSST_NW

FSST_NE_1

FSST_NE_2

Conclusions

PSST:

The intensity and unusual size of the SS are a result of the merging and amplification of a developing extratropical storm with SS.

FSST:

A bifurcation in response occurs for SS-like storms under a double CO2 warmer Atlantic SST

- **FSST_NW storms** : Follow a track similar to present day Sandy, but moving faster northward, making landfall north (~ 100-200 km) of its present land fall location; its destructive power and storm size more than doubled, and heavy rain by >50% of its present amount, bringing catastrophic damage from heavy rain and storm surge along the eastern Atlantic seaboard.
- **FSST_NE storms**: The storm intensified to a super hurricane over the Caribbean; the strong rotation causes the storm to recurve northeastward; interacts with the extratropical storm in a Fujiwara anti-clockwise rotation of twin vortices over the Northwest Atlantic. PDI and storm size are nearly tripled, and rainfall doubled compared to PSST.
- The initial extratropical storm only develops into a moderate disturbance, sparing the eastern Atlantic seaboard of major disaster. However, impact from extratropical “Sandy” substantially rejuvenated over warmer coastal water impacting extreme northeastern US and Canada (Maine and Nova Scotia)

Thank You